

## UTILIZATION OF LOW RANK COALS IN LIQUEFACTION

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### BACKGROUND:

Low rank coals constitute a large, low cost potential feedstock for producing transportation fuels in the United States. Low rank coal deposits account for about 48 percent of the demonstrated U.S. coal reserve base (see figure 1). The majority of the low rank coal reserves are subbituminous coals located in the Western U.S. in Montana and Wyoming. The lignite reserves are found in Texas near the Gulf Coast and in North Dakota.

Low rank coals are characterized by their high inherent moisture content and high oxygen content. Generally they are low in sulfur, and because of the high oxygen content they have a lower calorific value than bituminous coals. Figure 2 shows typical analyses for an Illinois bituminous coal and Black Thunder subbituminous coal.

Liquefaction of low rank coals is complicated by the high water content, and these coals must be dried before they can be slurried in the slurry mix tank to prevent excessive foaming. The high oxygen content requires that hydrogen be used to remove this oxygen as water and this can result in high hydrogen usage. In the past, low rank coals have been considered to be poor feedstocks for direct coal liquefaction, but considerable success in the processing of these coals was obtained by Anderson using the SRC-II process<sup>(1)</sup>. Figure 3 shows that overall coal conversions in excess of 95 percent were obtained with Big Brown Texas lignite, Indian Head Beulah Zap lignite, and Belle Ayr Wyoming subbituminous coals. These high overall conversions were obtained using iron pyrite as disposable catalyst.

Since that time, low rank coals have been processed in the two-stage liquefaction configurations at Wilsonville and at Hydrocarbon Research Inc. (HRI) with mixed success. Wilsonville has concentrated on using the thermal/catalytic approach with

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disposable iron catalyst in the thermal stage, while HRI has used their CTSL configuration with supported catalyst in each stage and no disposable catalyst addition.

#### **OBJECTIVE OF THE CURRENT STUDY:**

The objective of the current MITRE study is to estimate the cost of the coal derived liquid products that result from processing low rank coals in the Wilsonville and HRI CTSL configurations. The resultant cost of liquids is then compared to liquids produced from bituminous coals.

#### **METHODOLOGY:**

The methodology used to accomplish the above objective was to utilize the MITRE coal liquefaction cost model to assess the overall technical and economic performance of low rank coals in both the Wilsonville and HRI configurations. Actual test data from Wilsonville and HRI was used as the basis for these analyses. This test data is modified to simulate complete resid recycle extinction and to standardize the operating performance of the deashing unit. This corrected yield data is then used in the simulation models to predict the overall performance and economics of a conceptual commercial coal liquefaction facility.

The components of the MITRE two-stage direct coal liquefaction model are shown in figure 4. This computerized simulation model has been under development for several years, and has undergone continual improvement and updating as additional data become available. As part of this improvement, the overall plant configuration has been significantly altered since its initial documentation<sup>(2)</sup>. The original UOP/SDC integrated two-stage plant design<sup>(3)</sup> initially used in the MITRE model has been updated to include Shell gasification for hydrogen production, Kerr-McGee ROSE-SR units for deashing, and a combined-cycle facility for on-site electric power generation. In addition, the two-stage coal liquefaction section of the model has been improved by simulating the coal dissolution and resid upgrading reactors using first-order lumped kinetics. These kinetics are used to determine the required space velocities and resulting reactor volumes for the required coal conversions to specific product distributions. For the purpose of this analysis, the direct model has been extended to include naphtha hydrotreatment, distillate hydrotreatment and hydrocracking, and naphtha reforming.

The economic sections of the model provides estimates of the plant construction cost, total plant capital required, operating and maintenance costs, annual revenue required, and

required selling prices (RSP) of the products. Total plant construction cost is estimated by using cost data of unit operations obtained from various open literature sources. The unit operation cost data are scaled based on capacity, adjusted to the reference calendar year, and summed to give the total cost of construction. Total capital is calculated from the construction cost by adding engineering design and contingency costs, and funds used during construction. Addition of the non-depreciable capital (start-up cost, working capital, and initial catalyst and chemical cost) gives the total capital required. Gross annual operating costs are calculated as the operating and maintenance expenses minus the by-product credits. The annual revenue required is the sum of the capital and operating cost components. The capital component is calculated from a discounted cash flow (DCF) analysis using specified financial parameters. The RSPs of the products are then calculated from the total plant product outputs and the annual revenue requirement.

## RESULTS:

Figure 5 shows the technical performance data for several low rank coals that were obtained at Wilsonville and HRI. This data includes the test yield and the MITRE corrected yield for selected material balance periods in each run. In addition it shows the process operating conditions including the catalyst type and addition rates. The runs selected were Wilsonville 251 with Wyodak subbituminous coal<sup>(4)</sup>, run 255 with Texas lignite<sup>(5)</sup>, and runs 260<sup>(6)</sup> and 258<sup>(7)</sup> with Black Thunder subbituminous coal. There is also an HRI run included in the data set. This is run 227-27<sup>(8)</sup> with Wyodak subbituminous coal. These runs with low rank coals are compared in figure 5 to the results obtained in Wilsonville run 257<sup>(9)</sup> with Illinois bituminous coal. The yield data shows that the liquid yield is much higher with the Illinois coal than with the subbituminous and lignite coals.

Figure 6 shows the conceptual commercial plant summary data obtained from using the MITRE simulation model with figure 5 input data. The conceptual commercial plants are all sized to produce 100,000 barrels per day of raw liquid products. The resulting quantities of hydrotreated product and gasoline derived from the raw product is shown. The required selling prices of the products and the resulting equivalent crude price is also shown in figure 6. The standard economic parameters used to calculate the required annual revenue are shown in figure 7. These result in a capital charge factor of 0.167.

## **CONCLUSIONS:**

The use of low rank coals in conventional two-stage processing shows about a 10-12 percent decrease in required selling price of liquids compared to using Illinois coal. This is in spite of the much lower liquid yields from low rank coals, and results primarily from the much lower cost of the low rank coal. This RSP differential would allow a construction cost increase of about 20 percent to be at parity with the Illinois coal cost. However, it is expected that significant additional cost savings could be realized with low rank coals by using advanced processing techniques such as pretreatment and more effective disposable catalysts.

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## **DISCLAIMER**

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FIGURE 1.

# U.S. Demonstrated Coal Reserve Base

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(Billions of Tons)

Bituminous	255	IL, KY, WV, PA
Subbituminous	190	MT, WY
Lignite	48	MT, TX, ND
Anthracite	<u>7</u>	PA
Total	500	

FIGURE 2.

## Analyses of Feed Coals

	<u>Illinois #6</u>	<u>Black Thunder</u>
Molsture, wt% as det.	10.32	23.10
<u>Proximate, wt% Dry Basis</u>		
Volatile Matter	37.78	43.81
Fixed Carbon	50.68	48.89
Ash	11.54	7.30
<u>Ultimate, wt% MAF Basis</u>		
Carbon	80.46	73.53
Hydrogen	5.44	5.57
Nitrogen	1.62	1.01
Oxygen (diff.)	8.93	19.24
Sulfur, Total	3.56	0.65
HHV, Btu/lb MAF Basis	14165	12747

FIGURE 3.  
Results of SRC-II Processing of Low Rank Coals\*

Coal Name Seam	Big Brown Wilcox (Texas)	Indian Head Beulah Zap (North Dakota)	Belle Ayr Wyodak-Anderson (Wyoming)
Ash, Wt % MAF	11.40	10.15	7.16
Sulfur Wt % MAF	1.24	1.18	.64
Pyritic Sulfur Wt % MAF	.16	.52	.16
Iron Wt % MAF	.80	.64	.58
Run No.	440 RC**	440 RG**	467 RK**
Catalyst Added	0	0	0
Wt % Catalyst as (Fe <sub>2</sub> )	Pyrite III 2.9	Pyrite III 2.9	Pyrite III 5.16
Yields, Wt % MAF			
C1-C4	12.6	10.9	10.2
Total Oil	50.2	39.1	40.0
SRC	17.3	25.5	26.5
IOM	4.1	7.1	8.9
H <sub>2</sub> Consumed	5.1	3.3	5.5

\* Process conditions are 1-hour slurry residence time, 30 Wt. % Coal in slurry on 4% H<sub>2</sub> treat rate on coal.

\*\* Not steady-state

FIGURE 4.  
**Components of MITRE  
 Direct Coal Liquefaction Model**

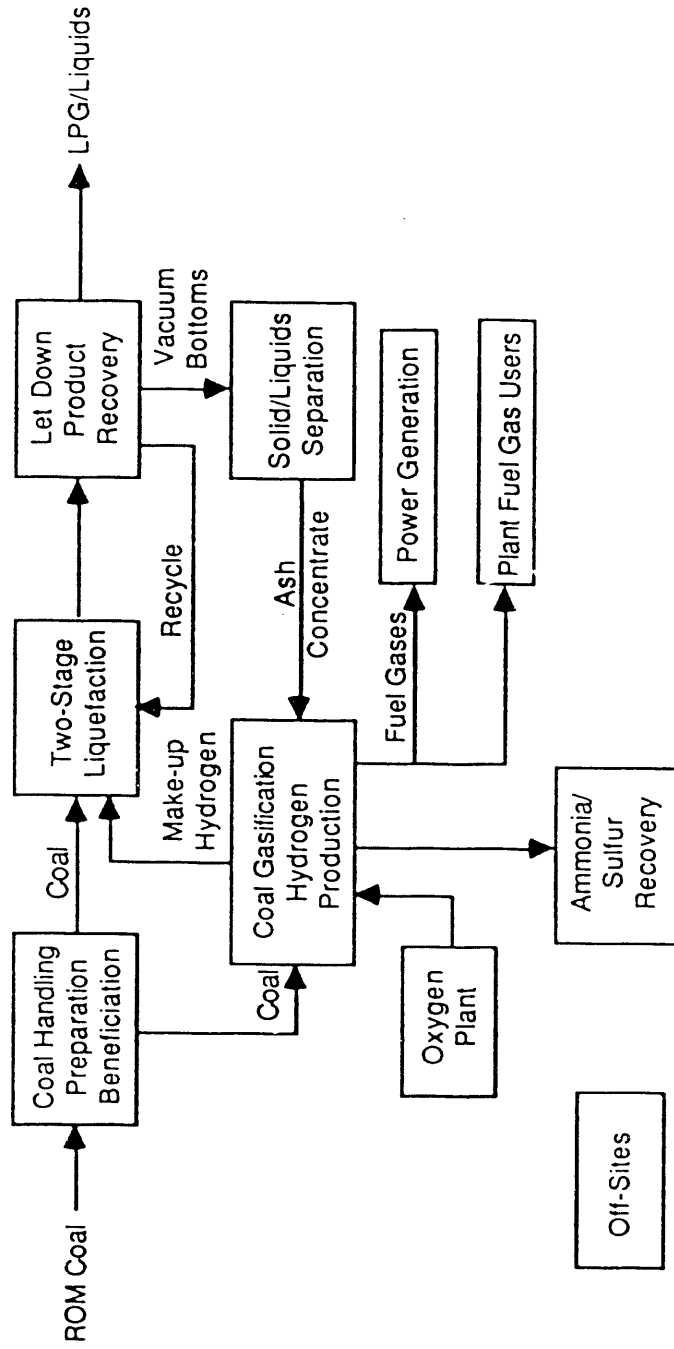


FIGURE 5

# Low Rank Coal Liquefaction Performance Data

COAL	Wyodak (Clovis Pt)		Wyodak (Clovis PT)		Martin Lake Texas Lignite		Black Thunder		Black Thunder		Illinois #6				
	Wilsonville 251-IIC	Test	Corrected	HRI 227-27	Test	Corrected	Wilsonville 255A	Test	Corrected	Wilsonville 258I	Test	Corrected	Wilsonville 257E	Test	Corrected
Yields WT% MAF															
H <sub>2</sub> Consumption	6.02	6.27	6.44	6.38	5.54	5.76	6.30	6.62	5.93	6.07	6.04	6.20			
Heterogases	23.46	23.51	23.02	23.01	23.60	23.63	22.80	22.86	20.70	20.73	13.93	13.96			
C1 - C3	7.05	7.21	8.04	8.00	7.59	7.74	11.19	11.42	10.29	10.39	4.68	4.79			
C4 - 350	19.33	21.71	19.05	18.46	14.58	16.38	4.30	5.02	18.00	19.20	15.79	16.90			
350 - 650	29.93	33.62	30.49	29.54	25.41	28.55	28.39	33.15	32.00	34.14	30.74	32.90			
650 - 850	9.11	10.24	11.99	11.62	9.06	10.18	21.30	24.87	8.10	8.64	19.94	21.35			
Soluble Reject	4.55	4.50	0	6.50	8.77	8.76	6.00	4.47	6.95	5.73	11.60	8.64			
Unconverted	4.70	4.70	9.87	9.87	9.94	10.09	4.70	4.70	7.22	7.22	7.21	7.21			
Coal															
Ash	8.78	10.28	9.63	9.63	13.88	16.18	6.60	8.70	7.87	9.97	12.96	12.96			
C4 - 850	58.37	65.57	61.53*	59.61	49.05	55.11	53.99	63.04	58.10	61.99	66.47	71.15			
Residual	7.09		4.59		6.14		7.50		2.61		2.14				
<b>CONDITIONS</b>															
1st Stage Temp	818		750		840		825		852					791	
2nd Stage Temp	745		820		730		790		790					760	
Cat. Addition	Batch		1.5		Batch		3.0		1.5					4.5	
Rate															
Catalyst Type	A-1C		A1-C/A1-A		Shell 324		Shell 324		Shell 324					A-1C	
Disposable Cat.	Fe <sub>2</sub> O <sub>3</sub> /DMDS		...		Fe <sub>2</sub> O <sub>3</sub> /DMDS		Fe <sub>2</sub> O <sub>3</sub> /DMDS		Fe <sub>2</sub> O <sub>3</sub> /DMDS					..	
Configuration/AR	Thermal/CaV/AR		CaV/Cat		Thermal/CaV/AR		Thermal/CaV/AR		Thermal/CaV/AR					CaV/CaV/AR	

\*975 end point

FIGURE 6.

# Commercial Plant Summary Data

COAL RUN #	Wyodak (Clovis Pt) Wilsonville 251-11C	Wyodak (Clovis Pt) HRI 227-27	Martin Lake Lignite Wilsonville 255A
Coal to Liquefaction (MTPDMAF)	23.1	25.5	28.0
Coal to Hydrogen	8.4	10.1	9.8
Total Coal	31.5	35.7	37.8
Coal Cost \$/ton (dry)	12	12	12
Total C4-850 (MAF)	65.57	59.61	55.11
Soluble Reject	4.5	6.5	8.76
Unconverted Coal	4.7	9.87	10.09
Plant Construction Cost (\$10 <sup>6</sup> )	3162	3336	3956
Total Capital Required	4847	5124	6093
Coal Cost	135.7	154.8	170.4
Other Operating Cost	303.3	320.7	419.4
Total Raw Product MBPSD	100	100	100
Hydrotreated Product	103	103	105
Gasoline	110	110	112
Relative Reactor Volume	1.23	0.91	1.92
lb H2/Raw Bbl	28.96	32.56	32.26
lb H2/Hydrotreated Bbl	29.83	33.80	33.32
Required Selling Price \$/bbl			
Raw Product	37.06	39.40	47.56
Hydrotreated Product	37.72	40.46	47.93
Gasoline	40.72	43.27	50.15
Equivalent Crude	31.01	33.45	40.03

FIGURE 6.

# Commercial Plant Summary Data

COAL RUN #	Black Thunder Wilsonville 260C	Black Thunder Wilsonville 258I	Illinois #6 Wilsonville 257E
Coal to Liquefaction (MTPDMAF)	26.1	24.7	22.9
Coal to Hydrogen	11.3	8.0	6.8
Total Coal	37.4	32.7	29.1
Coal Cost \$/ton (dry)	12	12	26.67
Total C4-C850 (MAF)	63.04	61.99	71.15
Soluble Reject	4.47	5.73	8.64
Unconverted Coal	4.70	7.22	7.21
Plant Construction Cost (\$10 <sup>6</sup> )	3644	3214	3197
Total Capital Required	5585	4914	4982
Coal Cost	158.1	140.0	290.2
Other Operating Cost	352.6	283.2	334.2
Total Raw Product MBPSD	100	100	100
Hydrotreated Product	114	104	110
Gasoline	122	111	118
Relative Reactor Volume	1.65	0.90	1.0
lb H2/Raw Bbl	34.54	30.04	32.16
lb H2/Hydrotreated Bbl	36.96	31.19	34.34
Required Selling Price \$/bbl			
Raw Product	42.94	36.99	42.39
Hydrotreated Product	44.32	37.87	43.51
Gasoline	46.33	40.78	45.75
Equivalent Crude	36.38	31.08	35.82

FIGURE 7.

# Economic Assumptions Used For All Analyses

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Equity	25 percent
Project Life	25 years
Tax Life	16 years
Income Tax Rate	34 percent
Price Escalation*	0
0 and M Escalations	0
Fuel Escalation	0
General Inflation	3 percent
Return on Equity	15 percent
Interest on Debt	8 percent
Construction Period	5 years

\*Escalation defined as inflation over and above general Inflation.

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